Space Technology Research Grants

Trajectory Tracking in Nonlinear, High-Order, Underactuated Robotic Systems

Completed Technology Project (2015 - 2019)

Project Introduction

Control of robotic systems, as a field, spans both traditional closed-loop feedback techniques and modern machine learning strategies, which are primarily open-loop. For certain applications, these domains do not intersect: traditional controls manage low-order, linear, and controllable/accessible systems with low-level feedback. For others that are complex, nonlinear, under-actuated, tightly coupled, and high order, machine learning can be used to find feasible open-loop trajectories. However, when adapting a machine-learned trajectory to a physical system, these domains collide, and occasionally leave embedded systems engineers with little recourse to make physical systems robust to disturbances in closed-loop. Such a situation occurs with systems for which traditional state space nonlinear controllers either cannot be developed or are computationally intractable, and for which a feasible trajectory is provided a-priori using another technique (e.g., machine learning.) The research described here may start to bridge this gap. This work seeks to develop techniques to perform analytic, closed-loop control around a given trajectory for a complex robotic system for which the analytically-derived dynamics are not formally controllable. Work at the NASA Ames Intelligent Robotics Group (IRG) and Robust Software Engineering Group has been investigating tensegrity (``tensile-integrity'') structures for a variety of low-cost, robust mission concepts. Tensegrity systems are nonlinear, tightly coupled, and often high order, naturally lending themselves as a case study for these control techniques. This work is targeted to the NASA Space Technology Roadmap TA04, Robotics, and the TAB of 4.5, Autonomy. Though tensegrity systems motivate this work, the techniques proposed in this research are expected to be applicable to a wide variety of autonomous or robotic systems that NASA develops. For example, motion of body of Robonaut in free space may be difficult to decouple from its manipulator dynamics. The tasks described in prior work for Robonaut 2 could be made more robust while also becoming more efficient and complex if this proposed method is combined with offline machine learning techniques. Based on these observations, I will perform the following investigation. I will develop, analyze, and test one or more methods for creating simplified/reduced-order, potentially hybrid, nonlinear models for approximate system descriptions with respect to both regions of a system's state space and also potentially for specific expected disturbances. This system identification work will dovetail with additional investigations into reachability-analysis-based control synthesis, and sum-of-squares control techniques. I will develop a general controller to wrap around these models, specifically for tracking a known trajectory. I will develop metrics for evaluation of these model-controller pairs, specifically with respect to disturbance rejection when tracking a trajectory, as well as for comparison to other techniques. I will perform such comparisons in both simulation as well as on physical hardware prototypes.

Anticipated Benefits

Trajectory Tracking in Nonlinear, High-Order, Underactuated Robotic Systems

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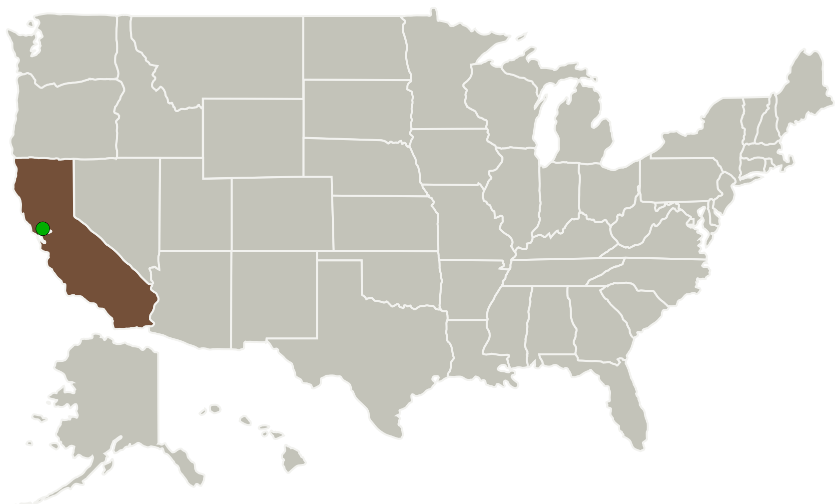
Primary U.S. Work Locations and Key Partners



Organizations Performing Work	Role	Type	Location
University of California-Berkeley(Berkeley)	Lead Organization	Academia	Berkeley, California
Ames Research Center(ARC)	Supporting Organization	NASA Center	Moffett Field, California

Primary U.S. Work Locations
California

Project Website:

https://www.nasa.gov/strg#.VQb6T0jJzyE

Organizational Responsibility

Responsible Mission Directorate:

Space Technology Mission Directorate (STMD)

Lead Organization:

University of California-Berkeley (Berkeley)

Responsible Program:

Space Technology Research Grants

Project Management

Program Director:

Claudia M Meyer

Program Manager:

Hung D Nguyen

Principal Investigator:

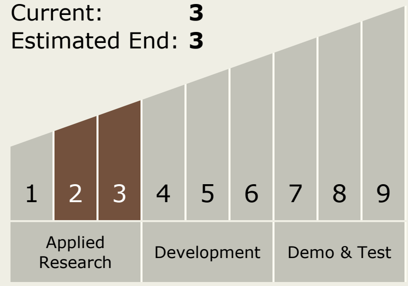
Alice M Agogino

Co-Investigator:

Andrew P Sabelhaus

Technology Maturity (TRL)

Start: **2**
Current: **3**
Estimated End: **3**



Technology Areas

Primary:

- TX10 Autonomous Systems
  └─ TX10.2 Reasoning and Acting
    └─ TX10.2.3 Motion Planning

Target Destinations

The Sun, The Moon, Outside the Solar System